



Modelling Electrical Resistance Tomography Using COMSOL and Matlab for Crack Detection Analysis

Siti Zarina Mohd Muji^{1*}, Khairul Akmal Zaini¹, Hanis Liyana Mohmad Ameran¹, Yasmin Abdul Wahab², Muhammad Nuriffat Roslee¹, Radzi Ambar

¹Faculty of Electrical and Electronic Engineering,
 Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA

²Instrumentation and Control Engineering department (ICE), Faculty of Electrical and Electronics Engineering,
 Universiti Malaysia Pahang, 26600 Pekan, Pahang, MALAYSIA

*Corresponding Author

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Abstract: Electrical resistivity tomography (ERT) is designed for prediction on electrode polarization, potential drop near current supply and electrode that proximate to phantom, electrode size, width, and length. ERT is felicitous to be utilized for an experiment on material that is conductive like concrete. The objective of this study is to model ERT sensor in two-dimension by utilizing COMSOL Multiphysics software. The study uses opposite method of electrode excitation for the analyses of the output voltage in the presence of air holes detection. The result of the electric field from the COMSOL is used further in the Matlab to reconstruct the image in the form of 64x64 pixels using Linear Back Projection (LBP) algorithm. ERT model is tested with the presence of one air hole or more. The same goes to the output voltage whenever the air holes are incremented. In conclusion, the opposite electrodes activation is suitable method to be considered because it produces the linear relation between the output voltage and the air holes.

Keywords: ERT, COMSOL, electrode excitation, opposite, crack.

1. Introduction

Building development is booming around the world and hence building quality is of paramount importance. The quality is based on the strength of a concrete mixture and compound materials such as cement, rough and fine aggregates, which are usually stone, sand, and water. At the same time, a development of concrete crack detector is thriving. A concrete crack detector designed specifically for various applications such as concrete and building management. The concrete crack detector is a device that can detect cracks in a concrete construction. In the construction industry, the device can detect the quality of concrete through the concrete cracking.

Positioning and installation methods for the automatic detection of the image surface cracked concrete has been proposed, but the existing methods have problems in practical terms. In order to detect cracks with image processing, cracks are usually defined by the characteristics of edge, regardless of the position and orientation are used. Otherwise, crack as sharp changes in gray scale values between the edge and the adjacent pixels that make up the outline and appear in the image as dark lines. Therefore, the edge is a unique feature that shows cracks. The rating on installation is extremely important to get an image that includes only the effectiveness of the concrete surface, but they do not work well when the image also include internal barriers. The reason for the poor performance in practice is that the actual

images on the site of concrete structures often include obstacles such as reinforcement corrosion due to carbonation or chlorination process in terms of building a cable or a peg leg and in the case of concrete pillars.

In this project, a concrete detector using ERT system is modelled using COMSOL Multiphysics. This modelling is the first step before the real hardware can be developed. Through modelling, the specification of the electrode or sensor can be further investigated.

Based on resistance data, an estimate of the distribution of the material can be obtained using the sensitivity map or model rules of physics detector. Model is very important in obtaining high quality and images with no noise. Therefore, engineers need to replace or add a building with sensors on the concrete. But, when the detector was placed permanently in the pipeline, it has caused difficulties for re-installation for concrete improvements.

Thus, the invention and new ideas for ERT have been created where the different size of concrete can be changed because it is flexible with no need to redesign the sensing module. In ERT hardware construction, it used the high cost and long time preparation. So, to reduce problems during construction, COMSOL Multiphysics software can help in this by building the hardware model according to design criteria and materials and displaying the reconstruct image by using Matlab software.

2. Related Research

The means used to detect cracks in the concrete is still the same as distributing electric current through the electrode and the receiver is used as ground. In this way, cracks can be seen or found more easily. Some software adds their technology with the technology of capturing images with cracks produced by emission electric current to the electrode ground. Non-destructive testing (NDT) is an analysis techniques used in science and industry to evaluate the properties of a material, component or system without causing damage [1]. The terms Nondestructive examination (NDE), Nondestructive inspection (NDI), and Nondestructive evaluation (NDE) are also commonly used to describe this technology [2]. Because NDT does not permanently alter the article being inspected, it is a highly valuable technique that can save both money and time in product evaluation, troubleshooting, and research. Common NDT methods including ultrasonic is commonly used in mechanical and electrical engineering. Innovations in the field of nondestructive testing have had a profound impact on tomography system.

2.1 Existing System

In modern technology, a lot of manufacturers produce some product with the highly specification, more reliable and affordable to the users. They come with some variance in the design of the product the main criteria to be commercialized. NTT's technology aims to examine and detect flaws in the state of the surface of a concrete structure, such as a concrete pole. Its unique analysis technology automatically excludes any interfering objects from an image taken using a digital camera, identifies object edges and detects even fine cracks. Since this technology allows a detection system to be built using only a digital camera and a PC, the system can be operated by anyone, without requiring any special qualification or skill.

Non-destructive inspection using image diagnosis software checks the surface of a structure or a product for flaws and aging without damaging it so that the inspecting entity can determine how to manage the object. This type of inspection is widely used to ensure quality control in the manufacturing industry and to ensure the safety of concrete structures and facilities, such as bridges, tunnels, and concrete poles. The market size for non-destructive testing may be estimated from the sales of those 133 members whose business is non-destructive testing in the Japanese Association for Non-Destructive Testing Industry [3].

Technology to process an image taken using a digital camera is attracting interest because it makes it possible to inspect and diagnose cracks in concrete structures automatically, safely, efficiently, qualitatively and with high precision. The image diagnosis software developed by NTT has been applied to safety inspections of concrete poles and underground cable tunnels, but can also be applied to the safety inspection of all types of concrete structures, such as bridges and buildings.

3. Methodology

In this project, MATLAB software is used to display the image reconstruction after collecting data voltage output from COMSOL Multiphysics. COMSOL is used to display voltage values resulting from the current injection from the hardware part via modeling. The resulting voltage value will be calculated as a whole in which these values will be generated on each electrode which was installed in concrete. The input will be from the output voltage generated from COMSOL software after completing the simulation of current flow in the concrete. A computer will also be used for simulation and presentation of the results of this project. Matlab software is used to display the sensitivity maps and reconstruct the image of concrete.

Then the image will be reconstructed at the computer and the real time monitoring can be viewed. Fig. 1 shows the block diagram of system development.

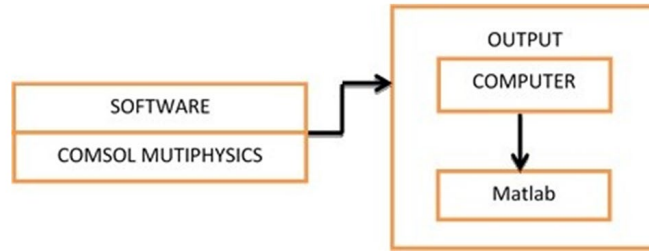


Fig. 1 - Block diagram of the system development

3.1 Software Development

Fig. 2 shows the basic software project implementation flowchart. It shows the flow to reconstruct the image. The process is started by creating a simulation software COMSOL. After the electrodes are injected with electrical current, the output voltage generated from the excitation will be used further to develop the sensitivity maps.

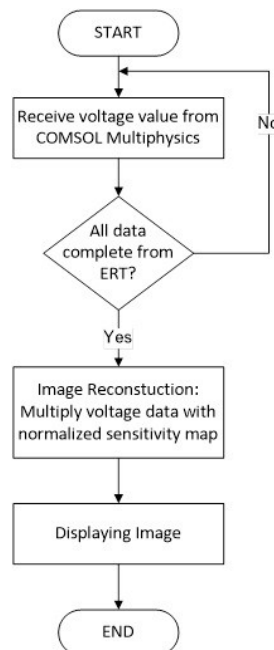


Fig. 2 - Basic software project implementation flowchart

Each voltage value received from the ERT will be multiplied by each normalized sensitivity maps where the goal is to produce the concrete image. The transmitter/electrode will excite the current and the voltage value that is produced by the receiver will be acquired by data acquisition unit until the completion of all expected data. From the COMSOL software, the interaction between transmitter and receiver will create the electric field and from this, the sensitivity map for all pair of transmitters and receivers will be summed up and normalized. The normalized sensitivity maps will be multiplied with the receiver's voltage to reconstruct the concrete image at the computer.

3.2 Procedure to develop material in COMSOL

COMSOL software is built to make a simulation on a variety of shapes and materials in which to make the analysis on a building project. This software can also be used to calculate or measure the voltage and current values that have been included in a project. The Application features COMSOL Multiphysics files pertinent to the electrical, mechanical, fluid, and chemical disciplines in which the user can choose any material they need to develop a project.

1. The first step is to build a sketch in COMSOL to determine which parts should be used as materials which have been assigned. The sketch can be made in 3D and 2D, where it is much easier for users to determine a project. This sketch should be the same as the hardware where the size of each material is in accordance with a predetermined size in Fig. 3.

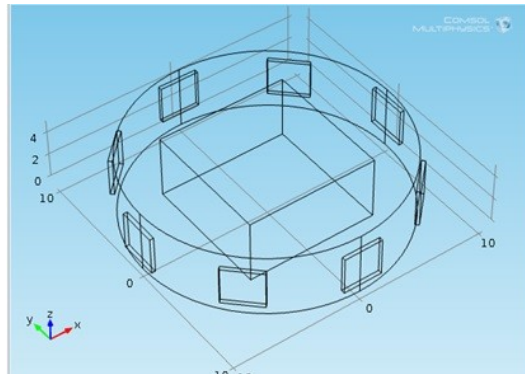


Fig. 3 - Sketch construction of concrete, electrode and air

2. Secondly, apply the concrete on the sketch was necessary. Each value in the concrete such as electric conductivity, relative permittivity should be included in the empty space of the materials that has been set. Value for electric conductivity is 1.7S/m and the value of relative permittivity is 4.5 [4].

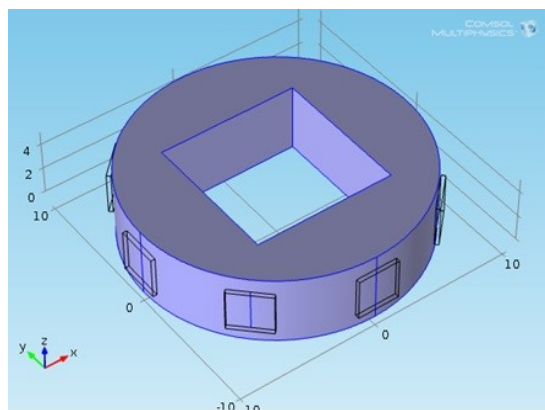


Fig. 4 - Concrete attachment

3. After that, the process to insert the electrode material on each pad around the concrete shall be made in accordance with the specified distance that is shown in Fig. 5. Each electrode has one terminal and one act as ground. The terminal electrode will convey the current through the concrete and will evade the air because air cannot transfer current through it. The current used in this project is 10mA.

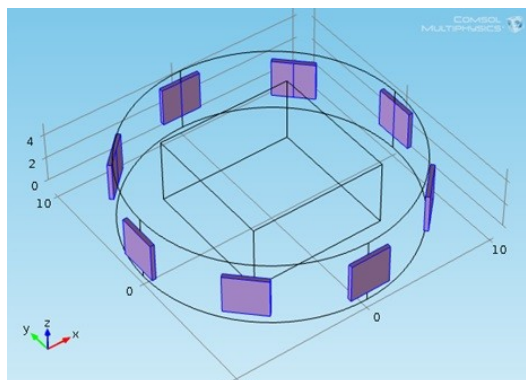


Fig 5 - Electrode attachment

4. The next step in Fig. 6 shows the entering process of the air into the sketch to make an example of cracking in the concrete. Values such as electrical conductivity and relative permittivity should be included following a set value. The air value for electrical conductivity is 3E-15 and relative permittivity value is 1.000536[5].

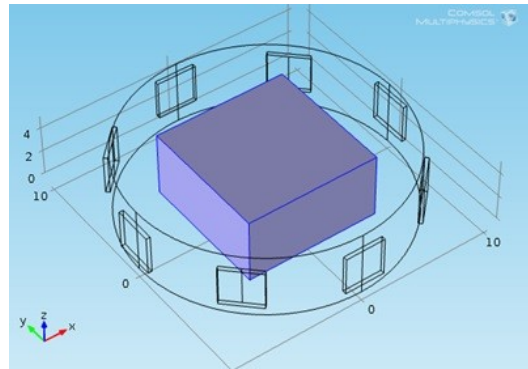


Fig. 6 - Air material attachment

5. Electric current is injected into one of the electrodes as much as 100mA will be used as a terminal and one of the electrodes adjacent to the terminal will be used as a ground. The electrodes are attached to the cylinder surface, and the current is injected between opposite electrodes. The electric current was injected between opposite electrode pairs, and corresponding to each current injection the voltages were measured between all adjacent electrode pairs. The red line indicated that the current flow from the terminal electrode to ground electrode which evading the air section.

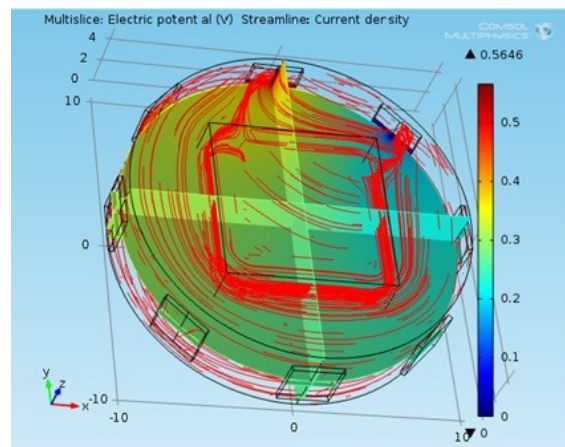


Fig. 7 - Current flow in streamline

The red line shows the path of electrical current is being positioned as a streamline where every passage of electric current that flows through all the concrete and then flow to ground. Fig. 7 is an example where the concrete that contains an air in a square shape.

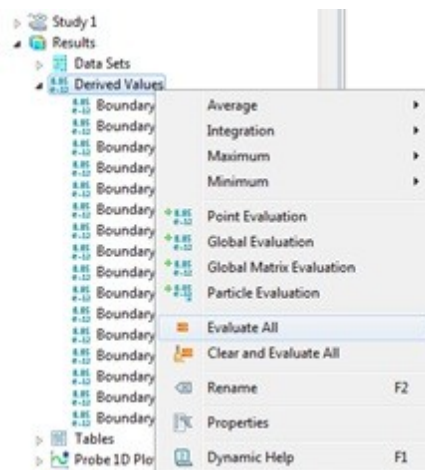


Fig. 8 - Evaluation step from Derived Values

6. Any form of phantom made of concrete that has been made will make less electrical current passing through the phantom. Although the phantom is air, electric current is still able to pass through the air space. This is because even if the electrical conductivity of the air is 0.5S / m and approaching zero, the electric current can pass through the air. The

value from excitation of pairs of the electrode can be evaluated by the derived value. Each electrode will produce a reading in pairs and they will be released after excitation electrode pairs carried on.

Fig. 9 shows the voltage reading in row 1 after evaluating the resistivity through the concrete. Each value is different according to the distance to the electrode that is being injected with the current.

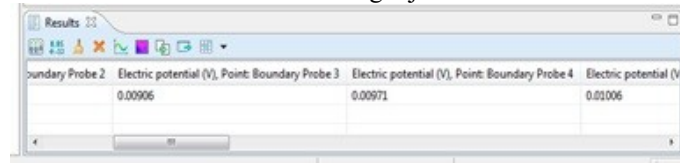


Fig. 9 - Result from voltage reading

3.3 Matlab

Matlab is used to calculate the normalized sensitivity maps where the total data is 64x64 pixel value. The reconstructed normalized sensitivity maps are the result of a combination of 40 different sensitivity maps that is produced after modeling process inside the COMSOL software. Each sensitivity maps will be stored in the form of an excel file where it will be recalled for image reconstruction process.

- Using MATLAB requires a file that has been compiled for inclusion in the software. Files that have been compiled into the M-Files from COMSOL will show the coding that contains all materials including the name of each electrode. M-Files also used to compile all the projects that have been created in COMSOL and will be re-extracted into Matlab.

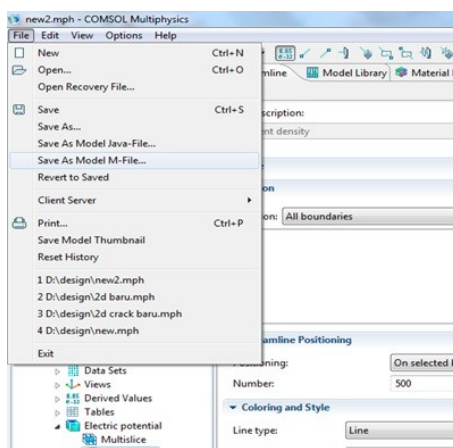


Fig. 10 - Compile into M-File

- Files that have been compiled will be loaded into the Matlab where it will be extracted in the form of coding. Fig. 11 shows the .m file that was included to be use in the Matlab. The coding which was built in COMSOL software will show the name of each electrode.

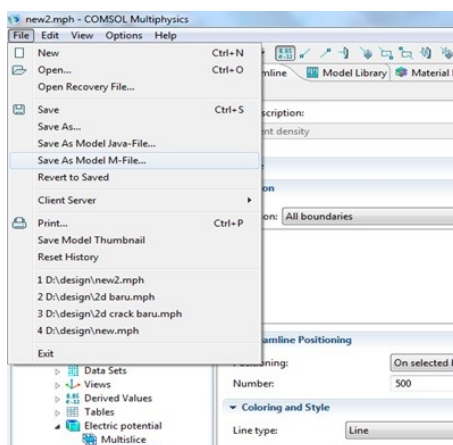


Fig. 11 - Load M-file into Matlab

M-Files that have been created in the form of COMSOL is intended to control a COMSOL Multiphysics model, without having to read this documentation. This is because such scripts can be auto-generated from the COMSOL

3.4.1 Sensitivity Maps

The sensitivity matrices are a representation of the sensor’s response to an individual stimulus in the sensing area. Although the sensitivity maps in ERT can be measured directly from the sensor using a material with different conductivity than the background and gathering the response from every electrode pair, a more practical and fast way to obtain the sensitivity maps is to calculate them from using the equation and test it in Matlab as shown in equation (3).

$$S_{ij}(x,y) = \int_{p(x,y)} \frac{\nabla E_i}{I_i} \times \frac{\nabla E_j}{I_j} dx, dy \tag{3}$$

where E_i is the potential due to i electrodes driving the current. E_j is the potential generated due j electrodes driving the current. I_i and I_j are the currents driven by each electrode pair.

To reconstruct the image, the normalized sensitivity maps should be produced using equation (4), (5). The combination of all independent projection electrode pair configurations is known as weight balance maps.

$$Wbmp = E_i * E_j \tag{4}$$

$$\bar{S}_{ij} = \frac{S_{ij}(x,y)}{Wbmp} \tag{5}$$

To get the Normalized Sensitivity Maps, values in a matrix form of Sensitivity maps must be divided by the Weight Balanced Maps. After the equation is inserted into Matlab, the image for sensitivity maps will be produced as shown in the Fig. 14.

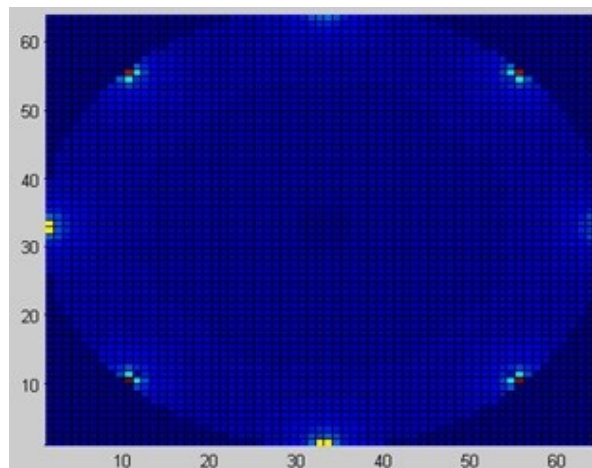


Fig 14 - Total projection of Weight Balance Maps

3.4.2 Result and Analysis

In this part, it will focus on the result from COMSOL Multiphysics and Matlab Software to produce the sensitivity maps and reconstruct the image. The analysis shows the difference value generated from each electrode using opposite method. The reading value is measured in voltage. The analysis made is intended to look at the concrete of various types of the hole that occur on the concrete. The resulting value will be issued in the form of a table for each electrode mounted on the concrete. In this part, the analysis will be made on 2 type of methods in 3 different sizes and location of the phantom to the concrete. The result is shown in 64x64 pixels reconstructed image. The value generated is measured and presented as normal concrete circumstances and the ventilation holes as shown in Fig. 15.

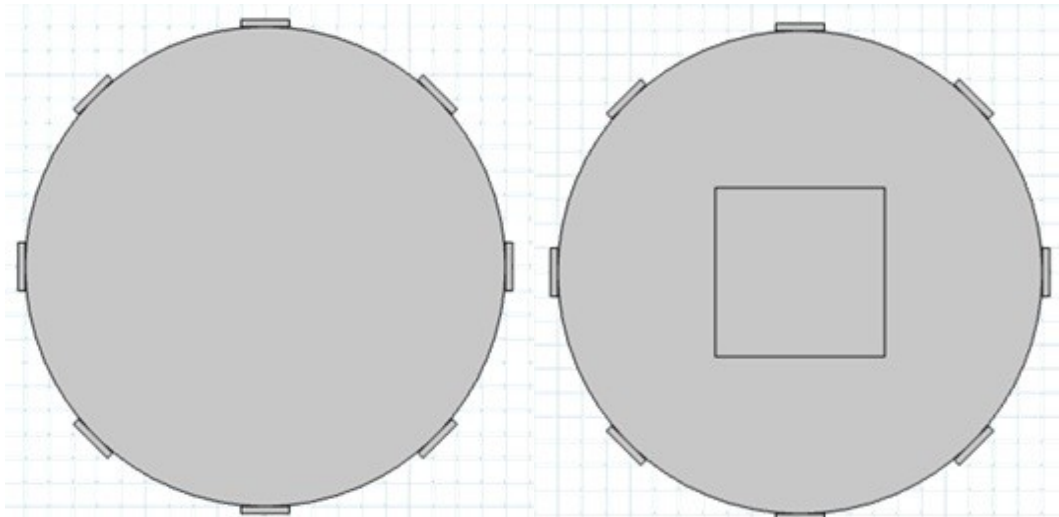


Fig. 15 - ERT sensors with 8 electrodes; (a) homogenous ERT; (b) Non-Homogenous ERT

4. Project Software

4.1 Output Voltage Using COMSOL

Fig.16 shows the COMSOL Multiphysics Software Interface where it can easily simulate all the situation needed by the user.

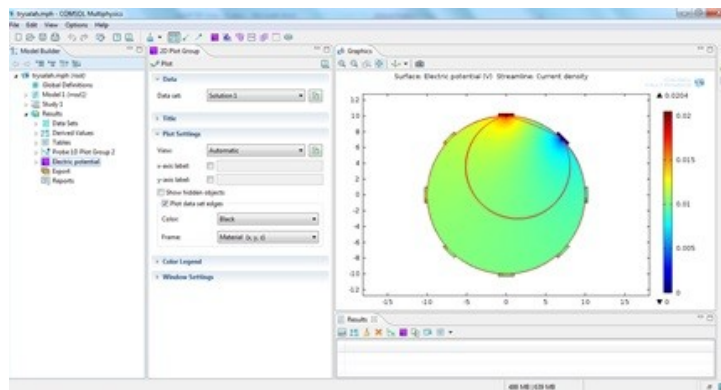


Fig. 16 - COMSOL Multiphysics Software Interface

In COMSOL software, the resulting values will be issued in the form of a .csv file that can be read by Microsoft Excel. The Electrical current injected in this software is 0.1A where it is the standard value for most concrete detectors. Once entered all the required material in COMSOL software, the modeling can be compiled. The resulting reading will be in form of voltage after the injection of electric current from the electrode. Fig 17 and 18 shows the result value and the result of line graph from COMSOL homogenous form (without any kind of phantom materials in the concrete).

Tx \ Rx		Tx							
		1	2	3	4	5	6	7	8
1	0.02044	0	0.00906	0.00971	0.01006	0.01036	0.01071	0.01136	
2	0.01146	0.02052	0	0.00916	0.00981	0.01016	0.01046	0.01081	
3	0.01078	0.01143	0.02058	0	0.00913	0.00977	0.01013	0.01042	
4	0.01041	0.01077	0.01141	0.02054	0	0.00911	0.00976	0.01012	
5	0.01018	0.01047	0.01083	0.01147	0.02059	0	0.00918	0.00982	
6	0.00973	0.01008	0.01038	0.01073	0.01138	0.02055	0	0.00908	
7	0.00903	0.00968	0.01004	0.01033	0.01068	0.01133	0.02041	0	
8	0	0.00908	0.00973	0.01008	0.01038	0.01073	0.01138	0.02041	

Fig. 17 - Example result from COMSOL

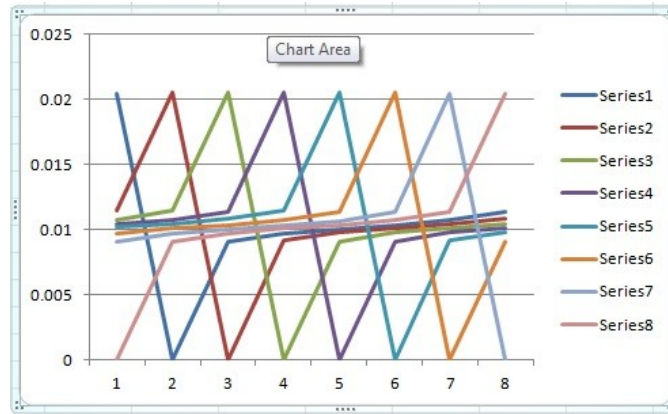


Fig. 18 - Result of line graph

4.2 Result From Opposite Method

Fig 19 shows the current density in the ERT without air hole where the electrode 1 acts as terminal and electrode 5 as a ground. The first electrode supplies the current of 0.1A and it will flow through the ground terminal and the concrete. The next electrode will continually read the voltage. When the air hole exists, the current density in concrete changes at all direction where the current will be diverted from the air hole as shown in Fig 20. The voltage difference can be seen in Fig 21 where it shows the difference when air hole detected higher output voltage reading on each detector.

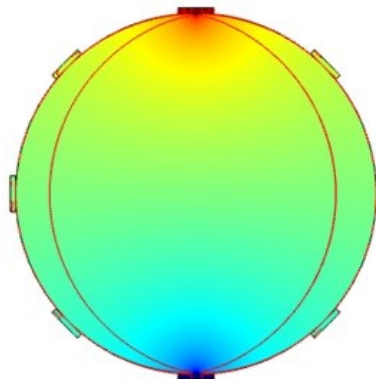


Fig. 19 - The current density in the concrete for the homogenous opposite activation

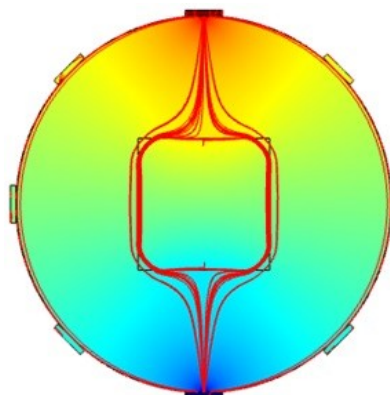


Fig. 20 - The current density in the concrete for the opposite activation with a single phantom

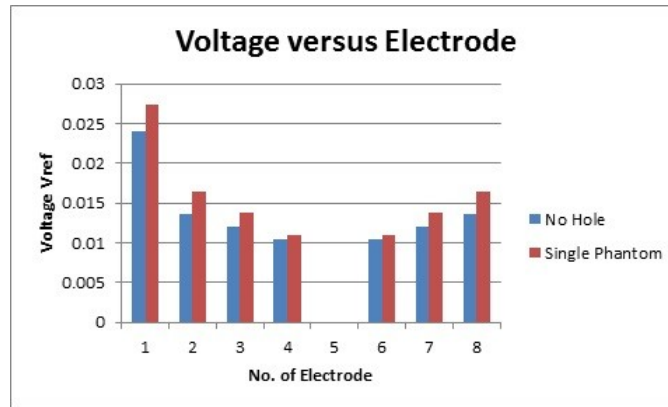


Fig. 21 - Output voltage versus electrode on no hole and single phantom

When the airspace is added to the concrete, the voltage will increase. This is because of the increase in the resistance of the concrete cannot cause the electric current through the area. Fig 22 and Fig 23 show the addition of two and three phantoms, where the current flow in the concrete barriers will also be reduced as a result of the airspace in the concrete. It can be concluded that the more air area in a concrete, the higher the value of the output voltage generated from each electrode as shown in Fig 24. The voltage reading from each electrode will produce different voltage values according to the size and position of the air space in the concrete.

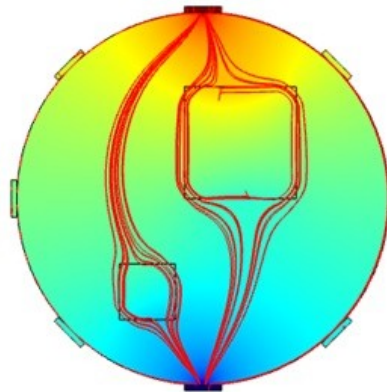


Fig. 22 - The current density in the concrete for the opposite activation with a double phantom

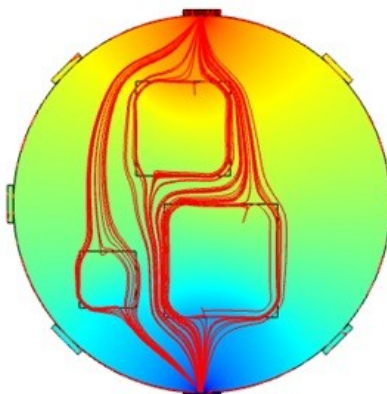


Fig. 23 - The current density in the concrete for the opposite activation with a triple phantom

Fig 24 shows the difference voltage value on each electrode. The voltage on the single phantom does not generate the high voltage because there was only one air area and it is far away from the electrodes. The voltage on the concrete with two airspaces has a relatively high voltage value because of the addition of air area in the concrete. This is because the air properties contain high resistivity so that the output voltage has the highest value. This is because the addition of up to three airspaces on the concrete causes the voltage to be increased. Furthermore, the airspace in the concrete is near to the excitation electrodes.

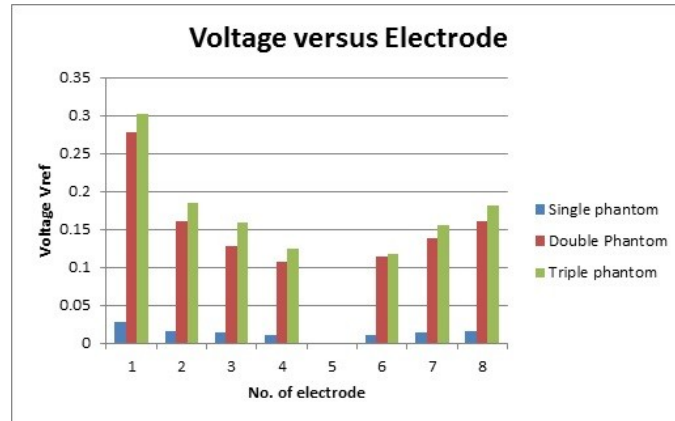


Fig. 24 - Comparison of the output voltage of the electrode to opposite electrode activation on the single, double, and triple phantom

Fig. 25, 26, and 27 show the phantom with variety of different sizes and positions of the airspace in the concrete. Each size and position of the airspace in the concrete play an important role in the production of image reconstruction. Fig 26 shows two airspace that differs in size and position inside the concrete. The airspace on the reconstructed image is slightly larger because it has a different air area at different positions even the small air space is located next to the other large air space. Fig 27 shows the airspace being located at bottom left. This is because most of the airspace in the concrete is located around the bottom left as shown in the image reconstruction.

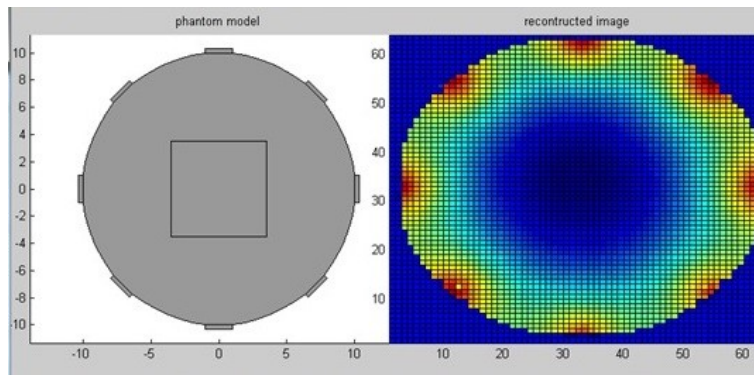


Fig. 25 - Reconstruct Image on Single Phantom

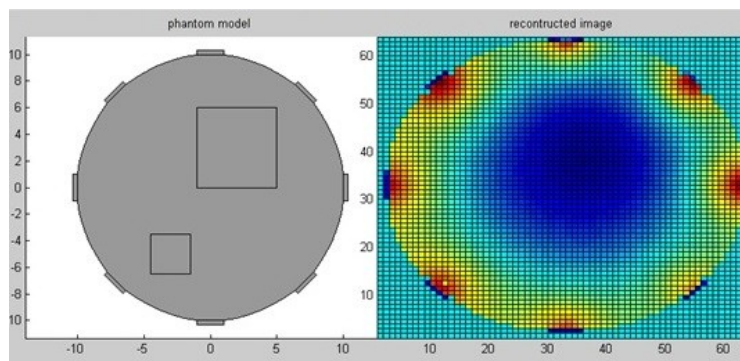


Fig. 26 - Reconstruct Image on Double Phantom

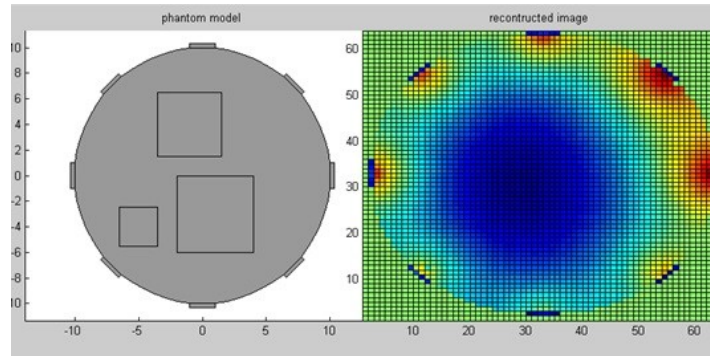


Fig. 27 - Reconstruct Image on Double Phantom

5. Discussion

The opposite electrodes activation method is the suitable method to detect the presence of air hole in the concrete. This is because the coordinates of the selected excitation electrodes and grounded electrode have long distances and create a lot of currents route. Furthermore, when the air holes present in the concrete, the detector electrodes can produce a high voltage value in line with the growing number of the air hole. A straight line that is generated through the opposite direction provides better access to the air area to get better image reconstruction. In addition, a high voltage value that is produced from each electrode is better to relocate the position of air in concrete.

Acknowledgement

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